

LABI – Laboratory of Mathematical Models

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Abstract. In the educational publications it is often pointed out that modeling is just another word for system understanding. Technically it can be regarded also as a system analysis. During teaching process examples usually play an important role to dynamical system understanding. To improve illustration possibilities, to encourage observation of system properties and to stimulate students' activity LABI (Laboratory of Mathematical Models of SISO and MIMO systems) graphical user interface has been developed in Matlab, through which illustrative examples and important analytical and some design functions can be accessed in a user-friendly way. They are organized in such a manner that they support and complement the lectures, exercises and students' activities which are basically organized through the so called seminars.

Mathematical/simulation models and/or experiments can be divided regarding different criteria. The starting examples are usually very simple (low order, linear, stable, ...), while several of them describe also real processes, some of them are connected with the pilot plants from our laboratories (Laboratory of Modeling, Simulation and Control and Laboratory of Autonomous Mobile Systems, Faculty of Electrical Engineering, University of Ljubljana, Slovenia).

To the set of models analytical toolbox has been added where the properties of the LTI models can be observed in a user friendly manner. These functions can be used for SISO or MIMO processes. Presented environment was well accepted by the students.

Introduction

At the Faculty of Electrical Engineering, University of Ljubljana, Slovenia, students can attend lectures Process Modeling (PM) and Dynamic Systems Simulation (DSS) in the sixth semester if they choose to study Automatics. Teaching activities are for both lectures simultaneous. To improve educational efficacy and to stimulate students' interest and their activity, several steps have been realized in the past few years.

Regarding the organization of the education process,

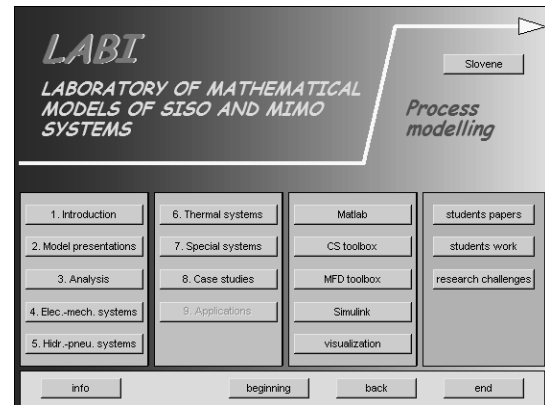


Figure 1. Starting window of LABI toolbox

first both lectures were very carefully synchronized so that the presented knowledge can be shared and combined. As the contents of both lectures are complementary, the proposed approach was of course very well accepted.

Exercises and computer-aided activities are performed by the use of Matlab and its toolboxes [1, 2] (mainly at least) as basics of this software are presented already in the second year of the study. In this way minimum preparation time is needed and students can in a very short time focus on problem solving.

At the beginning both lectures were finished by written and oral exams, which is a rather classical approach at university studies. But later on slow transition to the new form was realized. Now, at the end of the semester, several hours from both lectures (PM and DSS) are devoted also to the seminar work, which has to be prepared by each student. The tasks regarding this obligation are the following:

- problem introduction, suitable for modeling purposes;
- corresponding dynamical model description;
- transformation of mathematical model to simulation scheme;
- visualization and analysis of simulation results.

All prescribed tasks have to be presented in the form of conference paper and accomplished by the set of files, developed through problem solving. These results rep-

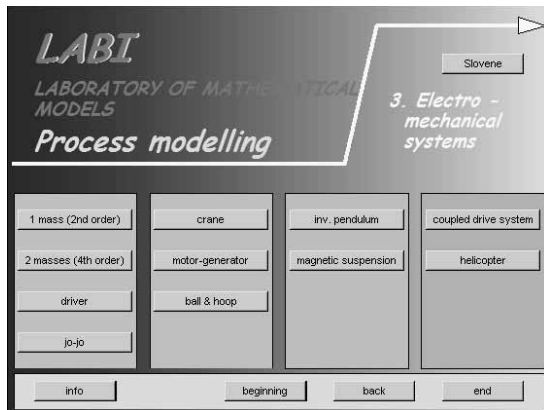


Figure 2. Examples of electro-mechanical group

resent part of exam of both lectures, but they still have to pass the oral part of exam regarding DSS and written part of exam of PM. In addition eight to ten best works are (as a reward) presented also at students' session of Electrotechnical and Computer Science Conference where this group of students can attend also the other sessions and presentations to obtain additional knowledge regarding research possibilities.

1 LABI – Laboratory of Mathematical Models

To support the lectures of Process Modeling and to improve corresponding exercises [3-6], as well as to indicate the links to DSS [7] also the so-called LABI environment was developed. The prepared possibilities can be observed by opening the first window of corresponding graphical user interface, as shown in Figure 1. Information available through LABI can be reached by simply pushing the prepared buttons. The first eight buttons – 1.) Introduction, 2.) Model presentations, 3.) Analysis, 4.) Electro-mechanical systems, 5.) Hydraulic and pneumatic systems, 6.) Thermal systems, 7.) Special systems, 8.) Case studies – also indicate the lecture's content. In the future some of the applications will also be added to illustrate the knowledge transfer to and from industry practice.

The buttons of the third column are connected to the files which offer short description of the main properties and potentially important features of Matlab, Control system toolbox, Multivariable frequency domain toolbox and Simulink in Slovene language. In the last year also a detailed description of visualization possibilities was added. It is also connected (through corresponding buttons) with the examples where visualiza-

tion is used for presentation and illustration purposes of modeling results.

In the last column the buttons

- enable the connection with the corresponding files which illustrate selected students' papers from the previous years (students' papers);
- enable the connection with the GUI where students can add and organize their own results, files and their paper (students work);
- and offer research challenges suitable for students (research challenges); these challenges indicate possibilities for further work which can end in different forms of student's competitions, papers or even diploma thesis.

Let's illustrate some possibilities of the group of electro-mechanical systems. When pushing the corresponding button the window opens, as presented in Figure 2.

This group consists of eleven examples, starting from a very simple one of the second order and finishing with seven examples of pilot plants from our laboratory [8]. First three devices (crane, motor-generator and ball & hoop) are stable SISO – systems, next two are unstable (inverted pendulum and magnetic suspension), while the last two are MIMO processes. Coupled drive system is stable and helicopter unstable one.

For all the examples mathematical models are developed. For the majority of examples they are in non-linear and also in linearized and/or in simplified forms so that also different approximations can be observed and compared. At the beginning testing is usually performed using simulation results which are often also animated.

In the case of ball & hoop process first the problem itself is described and presented schematically (Figure 3 – info button). From this presentation nonlinear mathematical model is developed (modeling button), using Lagrange equations. As for control purposes simple models are of great importance also linearized and simplified solutions are presented (linearization button). Several interesting simulation experiments can be executed using presented models where for better understanding also animation of system response can be observed at the same time (animation button).

One of the experiments is illustrated with Figures 4 to 7. In Figure 4 input sinusoidal signal is presented. This is voltage input at servo motor, which is connected with the hoop.

In Figures 5 and 6 hoop and ball – angles are given

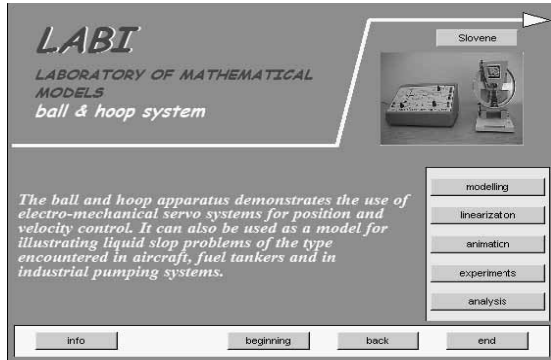


Figure 3. Ball & hoop system (TQ CE9) presentation

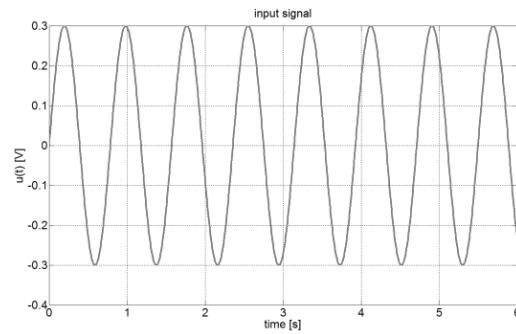


Figure 4. Input voltage signal

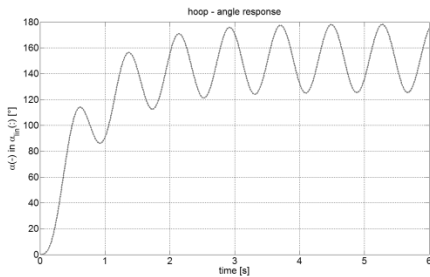


Figure 5. Hoop – angle response

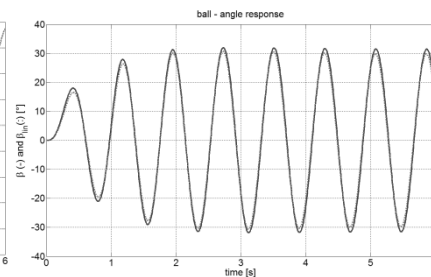


Figure 6. Ball – angle responses

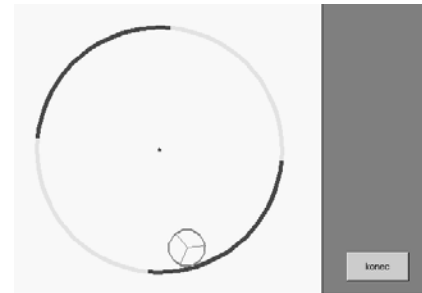


Figure 7. Picture from animation

regarding nonlinear and linearized (dotted lines) model, while in Figure 7 one picture from animation is snapped.

In the case of ball & hoop process (Figure 3) also simulation schemes are prepared (experiments button) which can be started on the computer in the laboratory (otherwise this button is not active) using the same input signals as in prepared simulation results. Mathematical model is in this case replaced with the block, which is communicating with the device in real-time using AD/DA converters. In this way also model validation can be undertaken.

When linearized system model is defined in Matlab also analytical toolbox can be started, as described in the next section.

Experiments from the other groups are organized in similar manner where in some cases also model operation is presented not only in open but also in closed-loop operation [9 – 11].

2 Analysis toolbox

When linear, time – invariant (LTI) mathematical model of observed process is defined in Matlab's working space also the analysis button becomes active and the user can observe system properties in some more details.

The Toolbox for dynamic system analysis [12] consists

of a number of functions which represent an extension and enlargement of the functions available in Matlab, Control System Toolbox, and Multivariable Frequency Domain Toolbox [13]. Several functions have been added, they are organized in graphical windows and can be executed also only by pushing the corresponding button. This is very important, especially when complex systems (like for example MIMO systems usually are) are observed. In such situation the user (especially inexperienced one) can very easily forget to test all important properties.

In all functions explanation and where possible graphical representation of results is added. The amount of additional comments can be controlled by the so called communication vector.

Mentioned functions can be divided regarding different criteria. Some of them can be used with SISO systems, some with MIMO and some are suitable for both groups of processes. Regarding different design situations both groups are organized into four levels.

Open-loop analysis functions use only the information of linear system model. They are grouped into general, time and frequency domain properties as illustrated in Figures 7 to 10. They should give the information of the properties of the process itself and help the user to decide if any improvement is needed, which can be real-

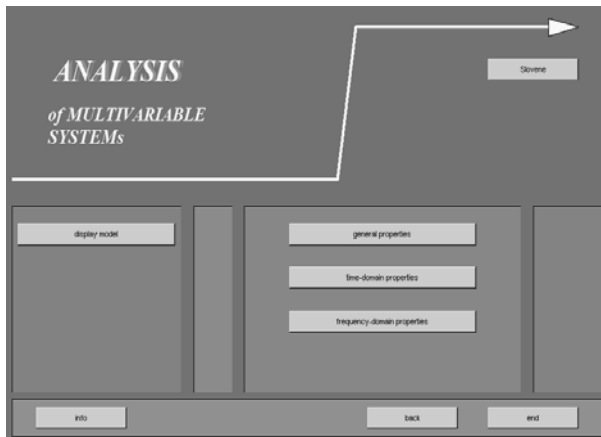


Figure 7. Toolbox for MIMO system analysis



Figure 9. Time – domain properties of MIMO system

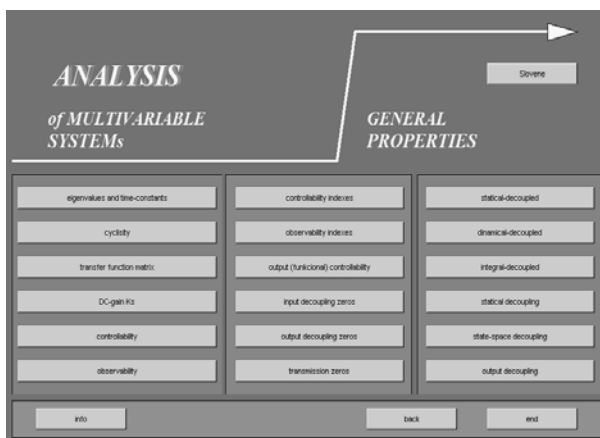


Figure 8. General properties of MIMO system

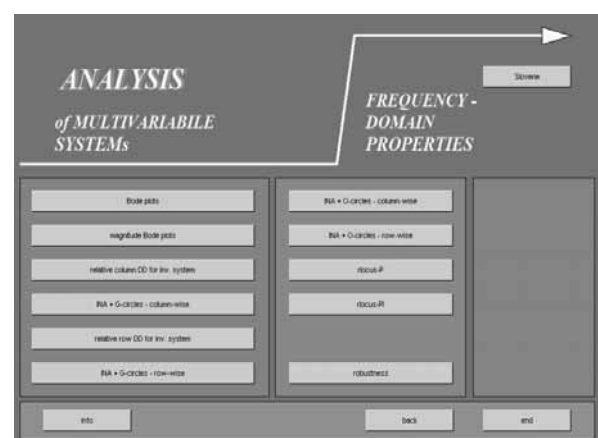


Figure 10. Frequency-domain properties of MIMO system

ized through process reconfiguration or by control design.

Closed-loop analysis functions are organized identically as open-loop ones, however in this case also the information of used controller is needed.

Absolute validation functions are used for evaluation of matching desired design goals, while in comparison with closed-loop analysis here also design goals have to be specified.

Relative validation functions tend to help the user to compare the efficacy of different design solutions and to prepare him/her to the real situation where also different kind of non-linearities have to be expected.

During the lectures of Process modeling only the first two groups are introduced, while absolute and relative validation are more important later, during control-design courses [14].

Important emphasis was devoted also to parallelisms and differences between SISO and MIMO systems.

When LTI - MIMO model is defined in Matlab's

work space, the user can observe the so called general system properties, which are calculated on the basis of system state – space description (Figure 8). Standard operations can define poles, time constants, cyclicity, transfer function matrix, DC-gain matrix, controllability, observability and corresponding indexes, input and output decoupling zeros and transmission zeros.

The last column in Figure 8 is specific for MIMO systems as corresponding functions inspect process interactivity. It is possible to find out if the system is statically, dynamically or integral decoupled. In addition it can be tested if the structure enable static or dynamic decoupling using state or output feedback.

Time – domain analytical functions (Figure 9) observe different systems' time responses, namely initial conditions responses, impulse and step responses, which are also one of the most frequently used testing signals. The second column functions represent direct extensions of usually observed step response properties of SISO systems, defined as delay time, rise time, maxi-

mum overshoot and settling time.

Among frequency – domain functions (Figure 10) it is important to mention Bode plots, direct and inverse Nyquist plots, which are also frequently used to define the so called diagonal dominance, which represents the measure of system cross – coupling.

As a parallelism to SISO root-locus MIMO root-locus was introduced when using a special structure of multivariable P or PI-controller [11, 12].

A group of functions is available also for testing system robustness.

3 Conclusions

In the paper organization of education process is presented for the students of the sixth semester who have chosen to study Automatics at the Faculty of Electrical Engineering, University of Ljubljana, Slovenia. During lectures Process modeling the so called LABI – graphical interface is introduced enabling simplified access to illustrative examples explained through lectures. Graphical result presentations and animations are also extensively explained through info – buttons online help in Slovene language.

When presented software is installed on the laboratory computers which are connected with pilot plants, prepared files can also be used for experimentation with real devices and for mathematical model validation.

As modeling is frequently used as a synonym for system understanding special attention is devoted to process analysis. Presented analytical toolbox can be accessed inside the same environment and enables very efficient work also in the cases of rather complex MIMO processes.

LABI – environment with its modeling examples, visualization and animation illustrations, analysis and sometimes also with closed – loop system operation was well accepted by the students who are now becoming also co-developers of presented toolbox.

In the near future the following improvements are planned:

- additional examples from industry practice, as it is very important for students to understand where the knowledge can be used;
- introduction of video clips illustrating laboratory work; in this way the problems can be made more realistic also in the lecture room;

- model validation on the basis of video clips using pattern recognition approach;
- complete dual representation in Slovene and English language.

References

- [1] *Using Matlab version 7*. The Mathworks Inc. 2005.
- [2] *Simulink, User's Guide*, The MathWorks Inc. 2005.
- [3] R. Karba. *Process modelling* (in Slovene language), Založba FE in FRI, 2nd ed., 2010.
- [4] D. Matko, R. Karba, and B. Zupančič. *Simulation and Modelling of Continuous Systems: A Case Study Approach*, Prentice Hall, 1992.
- [5] M. Atanasijević-Kunc. *Process modelling: Collection of examples in Matlab-Simulink* (in Slovene language), 3rd ed., Ljubljana, Založba FE in FRI, 2010.
- [6] M. Atanasijević-Kunc, Maja, A. Rakar. *Modelling and simulation, Laboratory exercises* (in Slovene language). 7th ed., Ljubljana, Založba FE in FRI, 2007.
- [7] B. Zupančič, R. Karba, D. Matko, I. Škrjanc. *Simulation of dynamical systems* (in Slovene language), Ljubljana, Založba FE in FRI, 2010, <http://msc.fe.uni-lj.si/Download//Zupancic/SIM.pdf>.
- [8] <http://msc.fe.uni-lj.si/Plants.asp>
- [9] M. Atanasijević-Kunc, R. Karba, B. Zupančič. *Multipurpose modelling in the evaluation of laboratory pilot plant*. Simul. pract. theory. 5, pp. 751-776, 1997.
- [10] S. Milanič, M. Atanasijević-Kunc, R. Karba, B. Zupančič. *Combination of two approaches to modelling of pressure-level pilot plant*. Proc., (ARGESIM Report, No. 11). Vienna: ARGESIM, pp. 63-68, 1997.
- [11] M. Atanasijević-Kunc, R. Karba. Hierarchically structured educational projects, WSEAS transactions on advances in engineering education, vol. 3, iss. 5, pp. 296-303, 2006.
- [12] M. Atanasijević-Kunc, R. Karba, B. Zupančič. *Toolbox environment for analysis and design of multivariable systems*. Preprints 6th IFAC Symp. on Advances in Control Education, Univ. of Oulu, Finland, Helsinki, pp. 305-310, 2003.
- [13] J. M. Maciejowski. *Multivariable Frequency Domain Toolbox, User's Guide*, Cambridge Control Ltd, and GEC Engineering Research Centre, 1990.
- [14] M. Atanasijević-Kunc, R. Karba, V. Logar, M. Papić, J. Bešter. *Student competition in multivariable control design - education through e-game*, Preprints 17th IFAC World Congress, Seoul, pp.12631-12636, 2008.